

Reduction of blast noise by a snow cover

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Experimental measurements were conducted to determine the effect of ground conditions near the source on blast noise levels. The measurements were conducted at two locations, one with temperate soil conditions and one with a seasonal snow cover. Pressure sensors were used to record the waveforms produced by the detonation of 0.57-kg charges of C4 explosive at distances between 10 m and 110 m. The measured blast waveforms were elongated and the peak amplitudes were significantly reduced at all distances when a snow cover was present. These measurements show that the interaction of the blast wave with the ground near the explosion is an important factor in the blast noise levels received at long propagation distances. This finding indicates that modification or control of the ground properties near military artillery training locations is a potential method of mitigating the noise produced by these activities. © 2002 Institute of noise Control Engineering.

Primary subject classification: 21.3.4; Secondary subject classification: 72.8

1. INTRODUCTION

Noise produced by military training activities such as artillery firing can lead to community noise complaints, but it is difficult to provide proper training using simulators or to produce mufflers capable of handling such large noise outputs as explosives or artillery.

In the past, mufflers, berms, and foams have been used in an attempt to reduce blast noise from artillery training,¹⁻³ yet these methods have not been satisfactory in part because of the very low frequency (tens of Hz) and long wavelength blast waves that artillery produces.

The effect of ground conditions on low frequency blast noise has been only occasionally investigated, as most studies have focused on meteorological effects important at long distances. Ford et al.⁴ compared measurements made over concrete and grassland, and found that the waveforms measured over grass had lower peak pressures and elongated waveforms compared to waveforms measured over concrete. Raspet et al.^{5,6} made blast measurements over temperate soils and modeled the waveforms using Delany and Bazley's empirical model of the ground impedance.⁷ These were the first full waveform calculations to explicitly include the porous ground effect. Cramond and Don⁸⁻¹⁰ also made full waveform comparisons, but for higher frequency rifle shots, using the Delany Bazley model.

The standard blast noise prediction model¹¹ was developed primarily to estimate blast noise from very large explosive charges at very long ranges. The model assumes "good" meteorological conditions (that is, downward refracting conditions) for propagation. The model does not allow different ground conditions to be investigated, although in the far field the model predicts that the peak pressure attenuates as $R^{-1.1}$, where R is the source-receiver propagation distance. This attenuation rate has been shown to agree with measurements made over grass for smaller explosive charges⁴ as well as higher frequency blank pistol shots.¹²

While porous ground impedance models are often applied to outdoor sound propagation, these efforts are usually at the higher frequencies (hundreds of Hz to kHz) of interest in traffic noise problems, etc. The two most popular ground impedance models are those of Delany and Bazley⁷ and Attenborough.¹³ While the Delany-Bazley model is simple to compute, it does not agree well with experimental data for low frequencies over snow.^{12,14} The more complex Attenborough model does agree with experimental data in this low frequency band.¹²

Low frequency blast noise waveforms measured over snow have been accurately modeled using Attenborough's ground impedance model for propagation distances of 100 m to 1400 m.¹⁵ These waveforms showed similar reductions in peak pressure amplitude and waveform elongations that were observed in higher frequency blank pistol waveforms. To date there have been no measurements reported for blast waves over snow at distances less than 100 m.

This paper presents measurements of explosive blast waves at distances from 4 m to 110 m over temperate soils and over a seasonal snow cover. These measurements were conducted to determine the effect of a porous snow cover on blast waves at very short propagation distances. If snow can reduce the noise produced by explosions at short distances, then modification of the ground near sources such as artillery fire may be a feasible method of reducing noise complaints from military training activities. The modification could be either the production of an artificial material that mimics the porous effect of a snow cover, or treating the ground to roughen the surface (e.g., by plowing¹⁶).

An earlier version of this paper was presented in Ref. 17.

2. EXPERIMENTAL METHOD

To determine the ground effect on blast noise, measurements were conducted at Blossom Point, Maryland, and at Fort Greely, Alaska over temperate soil and over a seasonal snow cover. (Two experiments were conducted in Maryland 10 months apart but the results were so similar that they are combined in the analysis presented in this paper.) The blast

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waves were produced by detonating single blocks (0.57 kg) of military C4 plastic explosives at a height of 1.5 m above the ground surface using an electric blasting cap.

In both experiments, an array of pressure sensors located 4 to 110 m away from the explosion was used to record the blast waveforms. Both solid state piezoelectric sensors (manufactured by PCB, Inc.) and B&K Model 4136 microphones located at the ground or snow surface and at a height of 1.5 m were used; the waveforms produced by the two types of sensors were identical. The measurements were initiated using a signal from the blaster box, and recorded with a Bison 9048 digital seismograph with a sampling rate of 5 kHz and a bandwidth of 3 Hz to 2.5 kHz. Calibrations of the sensors and recording equipment were conducted in situ to eliminate any possible temperature effects. Figure 1 shows a sketch of the measurement geometry.

During the acoustic measurements in Alaska, a snow cover ranging from 0.14 to 0.34 m in depth was present. The snow had been on the ground for weeks before the experiments were conducted, and consisted of a 0.07-m-thick wind crust with a density of 350 kg m^{-3} underlain by columnar depth hoar with a density of 120 kg m^{-3} . The permeability of the upper wind crust was $3.4 \times 10^{-10} \text{ m}^2$, while that of the lower layers ranged from 21 to $250 \times 10^{-10} \text{ m}^2$. These permeabilities correspond to acoustic flow resistivities of about 180, 30, and 2.5 kPa m s^{-2} .

Wind conditions were nearly calm during the tests and had little effect on the blast noise measurements. The only noticeable meteorological effect on the measurements was the slower wave arrivals observed in the winter caused by the lower air temperature (24°C in Maryland, -11°C in Alaska).

3. MEASUREMENT RESULTS

Figures 2 and 3 show examples of the experimentally recorded pressure waveforms. Figure 2 shows the waveforms recorded 10 m from the C4 explosion over temperate soil and over snow. Even at these very near distances (less than two

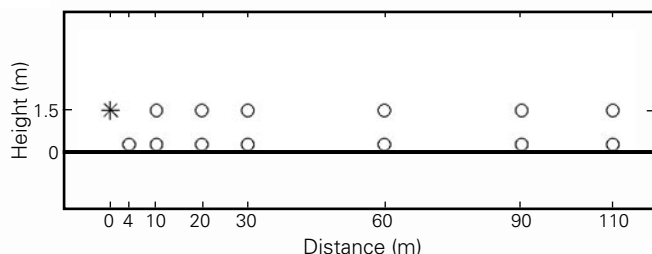


Fig. 1– Sketch of the measurement geometry. A single brick (0.57 kg) of C4 explosive (represented by the star) was detonated 1.5 m above the ground or snow surface and the resulting waveforms measured using pressure sensors at distances from 4 m to 110 m from the explosion. The pressure sensors were located at the ground or snow surface or at a height of 1.5 m above the surface. (Only a single ground sensor was used at 4 m to avoid damaging the sensors.)

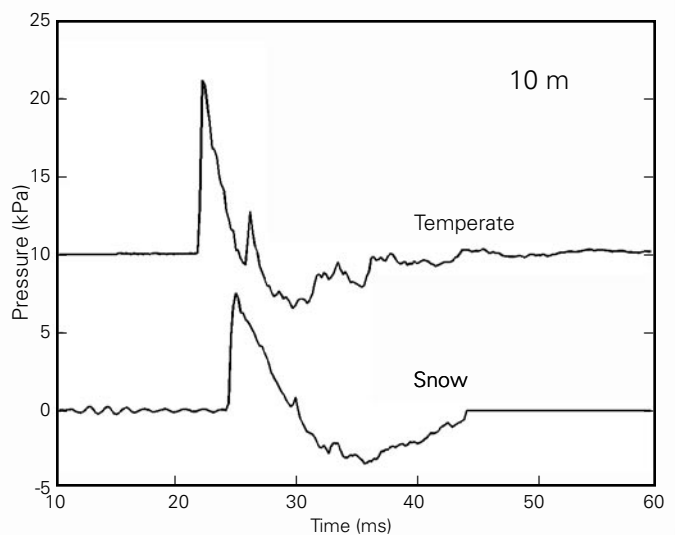


Fig. 2– Examples of pressure waveforms measured 1.5 m above the ground or snow surface 10 m from a detonation of 0.57 kg of C4. (Top) Waveform recorded over temperate soil in Maryland with a peak amplitude of 11.1 kPa. This trace has been offset by 10 kPa. (Bottom) Waveform recorded over a snow cover in Alaska with a peak amplitude of 7.5 kPa.

wavelengths at the peak energy frequency), the waveform recorded over snow has a lower peak amplitude (about 3.5 dB less) and the initial pulse is broader.

Figure 3 shows the waveforms recorded from the same shots at a distance of 90 m. The peak amplitude is now 9 dB

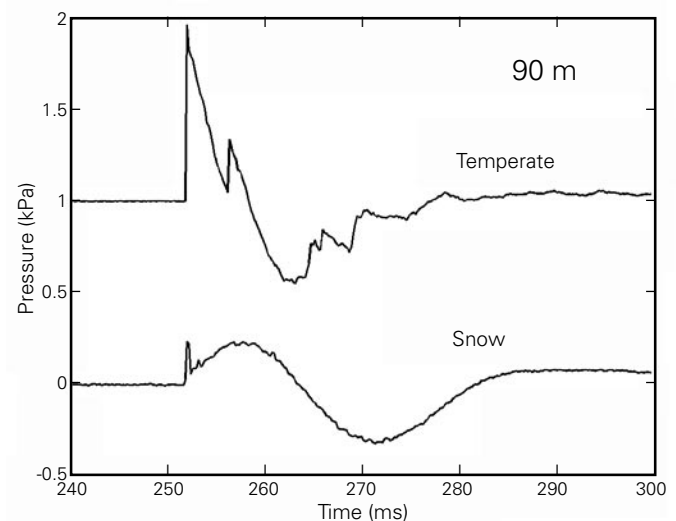


Fig. 3– Examples of pressure waveforms measured 1.5 m above the ground or snow surface 90 m from a detonation of 0.57 kg of C4. (Top) Waveform recorded over temperate soil in Maryland with a peak amplitude of 965 Pa. This trace has been offset by 1 kPa. (Bottom) Waveform recorded over a snow cover in Alaska with a peak amplitude of 235 Pa. This waveform has been time-shifted forward by 15.4 ms to align with the waveform over soil.

less and the waveform is much longer for the measurement over snow. In both cases, the arrival time over snow is slightly delayed with respect to the measurements over soil because of the lower air temperature.

The lower amplitudes and longer waveform durations are caused by the interaction of the blast wave with the porous snow cover. While these effects have been measured previously for acoustic pulse propagation over snow,^{12,15} measurements have not been previously made so close to the source and for such low frequencies.

Figure 4 shows the peak pressure amplitudes as a function of distance for the two different ground conditions. The scatter in the amplitudes for each measurement is caused mainly by different receiver heights, with the lower amplitudes measured at the soil or snow surface. The measured data are also compared to the predicted amplitude using the ANSI standard.^{4,11} The peak pressure levels in the measured data are always less than predicted, primarily because the standard, based on long range measurements (km and longer), does not accurately account for the ground interactions that occur at shorter ranges and higher frequencies. Even the soil is permeable enough to show these effects^{5,6} compared to the prediction.

The measured data in Fig. 4 show that the peak pressures measured over snow are always lower than those measured over soil, with a difference of almost 10 dB at 100 m. This difference represents a significant reduction of the noise when a snow cover is present. A least squares fit can be used to determine the attenuation coefficient α for each ground surface

$$P(r) = P_0 r^{-\alpha} \quad (1)$$

where $P(r)$ is the peak pressure at distance r , and P_0 is a reference pressure. The attenuation coefficient α is 1.30 for

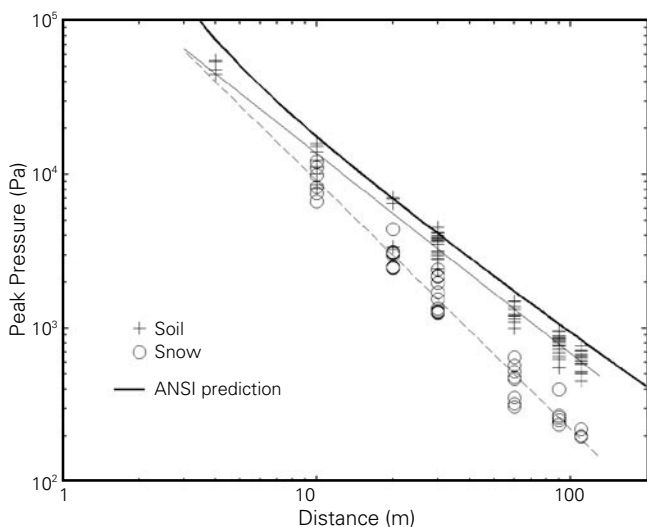


Fig. 4— Peak pressure vs. distance from a detonation of 0.57 kg of C4. The heavy solid line is the ANSI standard prediction.¹¹ Measurements over temperate soil (plus signs) and over a snow cover (circles). The thin solid line and thin dashed line are least squares fits to the measured data over soil and snow with slope -1.30 and -1.64 , respectively.

soil and 1.64 for snow.

The positive duration T_+ of a blast wave is a standard descriptive method for blast waves.^{18,19} Values for this parameter are shown in Fig. 5. The duration of the waves propagating over snow is about twice the duration of the waves propagating over soil.

The impulse of a blast wave is defined as¹⁸

$$I = \int_0^{T_+} p(t) dt \quad (2)$$

with units [Pa s], while the (C-weighted) sound exposure L_{CE} is defined as

$$L_{CE} = \int_0^{T_+} p_C^2(t) dt \quad (3)$$

with units [Pa²-s]. Here, $p_C(t)$ is the pressure time series after a C-weighting filter has been applied. These parameters were calculated from the measured data using Eqs. (2) and (3) and are shown in Figs. 6 and 7. The figures show that although the impulse is nearly identical for both types of ground, the C-weighted sound exposure is significantly higher for propagation over soil compared to propagation over snow. Since the sound exposure is one of the primary measures of human annoyance,^{20,21} this figure indicates that the snow cover does have a mitigating effect on perceived annoyance from the blast sounds.

4. CONCLUSIONS

Measurements of blast waves propagating over soil and snow show that the peak pressures produced by detonations of C4 explosive are reduced by about 5 dB when snow is present. Close to the source, the reduction can only be caused by the

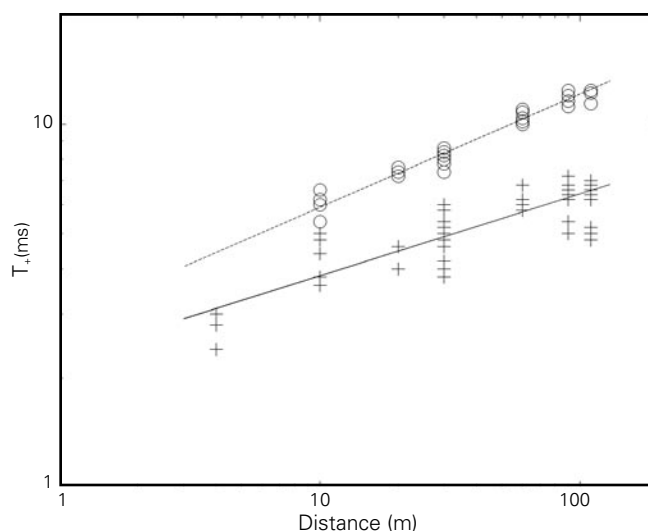


Fig. 5— Positive pressure duration (T_+) vs. distance from a detonation of 0.57 kg of C4. Measurements over temperate soil (plus signs) and over a snow cover (circles). The solid line and dashed line are least squares fits to the measured data over soil and snow.

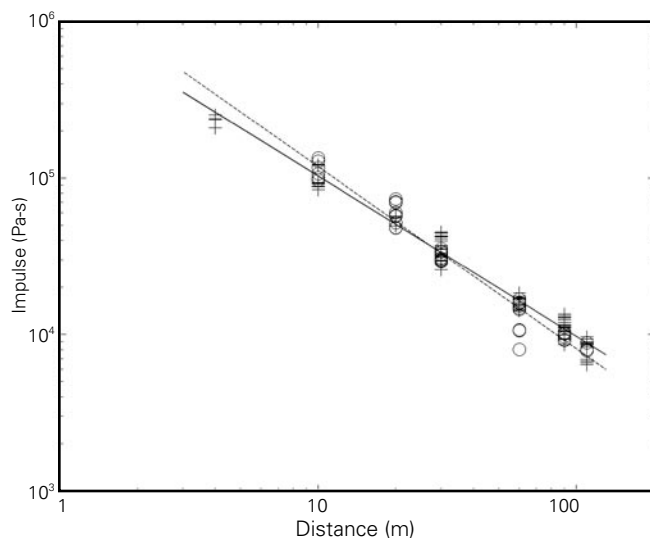


Fig. 6— Measured impulse vs. distance from a detonation of 0.57 kg of C4. Measurements over temperate soil (plus signs) and over a snow cover (circles). The solid line and dashed line are least squares fits to the measured data over soil and snow.

interaction of the blast wave with the porous snow surface. This observation implies that an artificial surface that can mimic snow's acoustic properties has potential for reducing the noise produced from artillery training activities.

Because of the elongation produced when blast waves propagate over snow, the measured impulse is nearly identical for propagation over soil or snow. However, the sound exposure is higher for soil than for snow, indicating a reduction in the perceived annoyance that would be experienced. Thus the snow cover does have a mitigating effect on blast noise.

5. ACKNOWLEDGMENTS

Steve Decato, David Carbee, and Dr. Joyce Nagle, CRREL, provided field support. Bill Davis and Jim Storey provided demolition support in MD and AK, respectively. The author thanks Dr. Keith Attenborough and two anonymous reviewers for helpful comments. Mr. Richard Andrejkovics, US Army PM-CCS, provided funding for the measurements and analysis. Additional funding was provided by the US Army ERDC BT25 and US Army ERDC AT24 projects.

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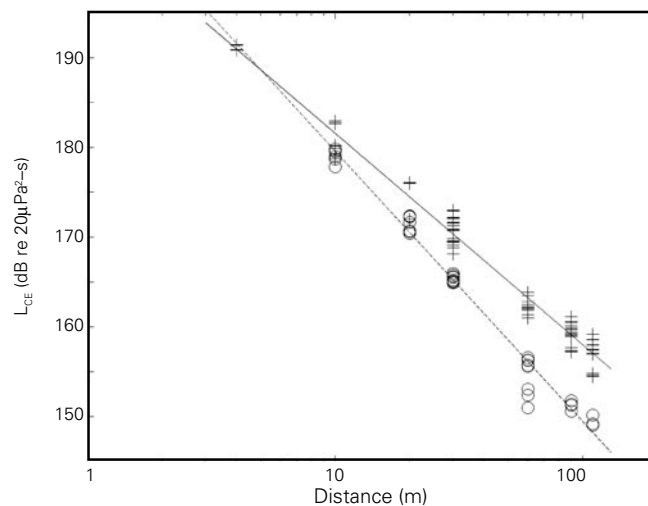


Fig. 7— Measured C-weighted sound exposure L_{CE} vs. distance from a detonation of 0.57 kg of C4. Measurements over temperate soil (plus signs) and over a snow cover (circles). The solid line and dashed line are least squares fits to the measured data over soil and snow. The exposure is about 9 dB less at 100 m distance when there is snow on the ground.

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